

Presenting and solving a sustainable multi-objective model of the hospital waste management supply chain during pandemic under fuzzy condition

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ABSTRACT

In this article, a four-objective mathematical model for the reverse supply chain of hospital waste management during the Corona epidemic in Iran is presented. The objectives of the presented model are: 1) Minimization of costs, including the cost of setting facilities up, waste processing, vehicle fuel costs, and environmental costs resulting from the emission of polluting gases; 2) maximizing the energy produced by burning waste; 3) Minimizing the risk of contracting the virus of non-management or mismanagement of waste and 4) Maximizing the amount of employment of labor in the established facilities. Due to the being multi-objective nature of the model, two multi-objective horse herd optimization algorithm (HOA) based on Pareto Archive and NSGA-II algorithm have been used to solve the problem. The results of solving the model showed that the proposed HOA algorithm is able to solve the model and achieve solutions with higher quality and diversity with an accuracy of 26% compared to the NSGA-II algorithm. Additionally, the comparison results of spacing metric and execution time of two algorithms show that NSGA-II algorithm searches the solution space with higher uniformity and solves the model in less time.

Keywords: Hospital waste management; Supply chain; Sustainability; Transportation; Covid-19; Healthy risk; Fuzzy programming.

1. Introduction

Since the industrial revolution, the amount and variety of waste has increased so much that it gradually became a very important issue. This significant growth of waste caused problems, the most important of which is related to the environment and the health of people in the society. Therefore, waste management attracted the attention of researchers and authorities, and various solutions were presented for how to collect, transport, process, recycle or destroy waste [24,26]. The waste related to healthcare is a type of waste that includes both hazardous and non-hazardous groups and a wide range of materials [24]. In other words, the term health and medical waste includes all the waste that is produced in health centers, research centers and laboratories related to medicine. In addition, the wastes that are produced in homes for the purpose of medical care are included in this category [24,25].

Therefore, designing a proper supply chain network to manage waste in the healthcare field is one of the main challenges of this field; because its lack of proper management, in addition to environmental pollution, hospitals and health centers will face serious problems. Improper disposal or handling of contaminated waste may transfer viral pathogens to treatment staff and recycling workers. It has been determined that due to improper disposal of medical waste, up to 30% of hepatitis B, 1-3% of hepatitis C and 0.3% of HIV are transferred from patients to medical staff [27].

As mentioned, hospital waste is one of the environmental problems that threaten the health of people and society due to the presence of dangerous, toxic and pathogenic factors. Therefore, it is very important to pay attention to the correct management of hospital wastes due to the potential of infection and the presence of dangerous wastes. Therefore, in this article, hospital waste management in Iran is discussed, and a multi-objective mathematical

model is presented and solved for the integration of location-routing decisions in the supply chain of health waste management under conditions of uncertainty and considering the dimensions of sustainability.

1.1. Study objectives

The objectives of this study are as follows:

Main objective: Providing an integrated location-routing in the supply chain of hospital waste management in pandemic conditions, taking into account the dimensions of sustainability under uncertainty condition.

Special objectives: (i) Identifying the concept model of hospital waste management supply chain. (ii) Determining the supply chain's level and communication among them. (iii) Identifying the parameters of the hospital waste management problem. (iv) Designing a mathematical model for locating and routing the supply chain of hospital waste management during pandemic. (v) Considering sustainability and uncertainty in the mentioned problem. (vi) Designing and implementing a meta-heuristic algorithm structure to solve the model. (vii) Data gathering, solving model and analyzing results.

2. Literature Review

Osaba et al. (2019) used the improved discrete bat algorithm to solve the problem of distributing medical goods and collecting medical waste. In their paper, the cluster vehicle routing problem was modeled considering simultaneous delivery and pickup, asymmetric variable costs, forbidden roads, and cost constraints. They also applied the bat algorithm to solve the model. In the mathematical model presented by them, the levels of drug distribution centers, hospitals and health centers were considered, and vehicles with limited capacity collected waste at the same time as they deliver medicines to hospitals and health centers [1]. Gergin et al. (2019) addressed the problem of locating sanitary waste disposal facilities using the artificial bee colony algorithm. In their paper, an artificial bee colony-based (ABC-based) clustering algorithm was proposed to solve the problem of locating multiple facilities. Unlike the original version, which is applied to multivariate data clustering, ABC-based clustering solved two-dimensional clustering. On the other hand, the multiple facility location problem that the proposed clustering algorithm dealt with was aimed at finding site locations for healthcare waste [2].

Yusuf Çetinkaya et al. (2020) investigated medical waste management in a city with a medium population in Turkey and developed a medical waste prediction model. They used a regression model to estimate the amount of waste produced by hospitals in Aksaray city. The inputs of the model were the number of patients in three different age classes (0-15; 15-65; 65) [3]. Ashtari et al. (2020) studied the improvement of health and medical waste management, characteristics and results in a systematic review. In their article, the required data was obtained by searching keywords such as waste management, biomedical waste, hospital waste, healthcare waste, infectious waste, medical waste, waste disposal facility, waste, waste disposal facility, in PubMed, Scopus, EMBASE, collected. Google Scholar, Cochrane Library, Science Direct, Web of Knowledge, SID and MagIran and manual search in journals, referencing and searching in literature between 2000 and 2019 were used [4]. Saeidi et al. (2020) presented a two-level meta-heuristic approach for the problem of hazardous waste management. Their paper focused on the design of a medical waste management system with a hierarchical structure, including a local government and a waste management planner. The high level was for designing and controlling waste management

facilities by minimizing the environmental risks associated with medical waste disposal. While, the lower level model was to determine garbage collection plans only by minimizing its total operating costs. Therefore, this study developed a two-level mathematical model in which the benefits of both stakeholders were considered. Also, a two-level meta-heuristic approach based on genetic algorithm was used to solve the model [5].

Kargar et al. (2020) designed a reverse logistics network to manage medical waste during the outbreak of the corona virus epidemic. In this research, a linear programming model with three objective functions was developed to minimize the total costs, the risk associated with waste transportation and treatment, and the amount of uncollected waste. Also, several functions that calculate the amount of produced waste according to the parameters of the current epidemic were proposed. To solve the multi-objective model, the revised multi-option goal programming method was used, and a real case study from Iran has been investigated to show the validity of the proposed model. The final results show that this model can balance the three objectives by determining the flow between centers, deciding to install two new temporary treatment centers, and allowing the network to have uncollected waste [6]. Yazdani et al. (2020) addressed the location of medical waste disposal facilities and used a multi-criteria decision-making approach for this issue. They used the new best and worst option method with interval approximation numbers to decide the sanitary waste disposal location and presented a case study in a private hospital in Madrid to demonstrate the application and the effectiveness of the proposed multi-criteria evaluation method [7].

Yu et al. (2020) designed a reverse logistics network for the effective management of medical waste during the Corona period in Wuhan (China). This paper proposes a new multi-objective mixed-integer program for reverse logistics network design in epidemic outbreaks, which aims to determine the best temporary facility locations and transportation strategies for effective medical waste management. Also, in this paper, several general policy recommendations are presented based on computational experiments and quantitative analysis. The results of the paper show that the installation of temporary incinerators may be an effective solution to manage the extraordinary increase of medical waste during the outbreak of COVID-19 in Wuhan, but the location selection of these temporary incinerators is of considerable importance [8]. Nikzamir and Baradaran (2020) designed the healthcare logistics network considering the random spread of pollution and presented a bi-objective model for it. In the proposed problem, the location of the centers was taken into account and a random function was considered for the spread of pollution, which depends on the time of transmission. In this regard, the transfer time between medical centers was considered as a normal random variable. As mentioned, they presented a two-objective mathematical model under conditions of uncertainty (random) and used the multi-objective cascade algorithm based on the Pareto Archive to solve the model [23].

Nikzamir et al. (2021) presented a bi-objective mathematical model for infectious waste management. In the proposed model, in addition to minimizing the costs of the chain, reducing the risk of the population exposed to the spread of contamination caused by infectious waste was also considered. For this purpose, they created a multi-level supply chain, taking into account the green routing-location problem, in which the location of recycling, disposal and refining centers with different refining technologies and the routing of vehicles between the refining and hospital levels were discussed. The issue of routing was considered many times and the criterion of reducing

fuel consumption of heterogeneous vehicles was used for green routing. Finally, a unified meta-heuristic algorithm based on colonial competition algorithm and genetic algorithm was developed [24]. Wang et al. (2021) presented a multi-objective and multi-period optimization model for the design of the reverse logistics network of municipal sanitary waste. This paper conducts a two-stage reverse logistics network design for municipal sanitary waste. The first step involves predicting the amount of medical waste. They used the gray GM(1) prediction model to predict the amount of medical waste in several periods of target hospitals. In the second step, a multi-objective model aims to minimize operating costs and minimize environmental impacts for facility allocation decisions, which includes the configuration of important facilities such as hospitals, collection centers, transfer centers, processing centers, and sites [9].

Lotfi et al. (2021) designed the chain network of medical waste by considering risk and stability. They proposed a mathematical model based on Steward and Step Stochastic Programming that takes into account flexibility (network flexibility and complexity) and sustainability requirements (energy and environment). One of the things that they considered in their model is risk minimization and they used the conditional value at risk approach to measure risk. Also, the model was solved with the GAMS and CPLEX solver. Their results showed that with the increase of the conservative factor, the confidence level of CVaR and the waste recycling factor, the cost function and the risk of the population increase. In addition, the increase in demand and problem size increases the cost function [10]. Liu et al. (2021) researched the optimization of the health and medical waste management system based on the principle of green governance in the COVID-19 pandemic. This paper analyzes and studies the principles of green governance and summarizes the problems in the current sanitary waste management system. Through the creation of temporary warehouses along transit routes, digital simulation and bionic experiments were conducted in the Hongshan District of Wuhan to improve the efficiency of sanitary waste transportation. In addition, this study discusses the coordination and cooperation of the government, hospitals, communities and other sectors in the process of sanitary waste disposal, and suggests guidelines for sanitary waste disposal throughout the country in order to deal with possible risks and provide effective references in all areas [11].

Shadkam (2021) designed a network for the management of COVID-19 waste and network optimization using the cuckoo optimization algorithm. He designed the reverse network of medical waste management and presented a single-objective mathematical model with the aim of minimizing costs. He also used Cuckoo's meta-heuristic algorithm to solve the model [12]. Mishra and Rani (2021) studied the location of medical waste disposal facilities using a multi-criteria decision-making approach. In order to locate, they first determined the important and effective criteria and indicators, and then, based on a fuzzy decision-making approach, they located facilities with limited capacity [13]. Valizadeh et al. (2021) investigated mathematical modeling for energy production from hazardous waste during the COVID-19 pandemic. In their study, a hybrid mathematical modeling approach including a two-level programming model for infectious waste management was proposed. At the higher level of the model, the government's decisions about the total costs of infectious waste should be minimized. At this level, the collected infectious waste is converted into energy, the income from which is returned to the system. The lower level is related to the risks of virus transmission through infectious waste, which can be catastrophic if ignored. Their study considered low, medium, high and very high prevalence scenarios as key parameters for waste generation [14].

Govindan et al. (2021) presented a mathematical model for medical waste management during the outbreak of the coronavirus disease. This paper developed a bi-objective mixed integer linear programming model for medical waste management during the COVID-19 outbreak. The proposed model minimizes the total costs and risks simultaneously. This paper considers for the first time some realistic assumptions, including location routing problem, time window-based green vehicle routing problem, vehicle scheduling, vehicle breakdown, delivery, population risk, and fuel consumption dependent on Burden for infectious and non-infectious management. They used a fuzzy goal programming approach to solve the bi-objective model using data related to 13 medical waste production nodes in a proposed location in the west of Tehran [15].

Polat (2021) designed a mathematical model for medical waste management during the coronavirus outbreak. This paper presented a research hypothesis as to whether effective medical waste management would prevent potential impacts of the 2019 coronavirus disease-related waste issues on the city-wide environment. This study for the first time determined optimistic, realistic and pessimistic scenarios of uncertain waste generation using time series analysis method and waste generation formula [16].

Tirkolaee et al. (2021) studied the management of sanitary waste in the period of Covid-19 and presented a robust fuzzy multi-trip routing-location problem in the medical waste management system during the outbreak of COVID-19. The mathematical model presented by them is multi-objective and the objectives are to simultaneously minimize the total travel time, the total violation of time windows/service priorities and the total pollution/environmental risk imposed on the population around the disposal sites [17].

Ahmed et al. (2021) have addressed the issue of sustainable production policies and waste management for medical equipment for COVID-19 in conditions of uncertainty. This paper proposes a modeling and optimization framework for sustainable manufacturing decision making and waste management for medical equipment of the COVID-19 era under uncertainty. To quantify the uncertainty between parameter values, the theory of intuitive fuzzy sets is used and a robust ranking function is presented for it [18].

Tarkaish et al. (2021) have studied multi-objective optimization for the design of healthcare waste management network with a sustainability perspective. This paper formulates a new multi-objective optimization model to enable companies to make optimal decisions considering economic, environmental and social aspects. In the proposed model, the first objective function aims to minimize transportation costs, processing costs and establishment costs. The second objective function aims to minimize environmental risks and greenhouse gas emissions related to waste transportation between facilities. The third objective function aims to maximize employment opportunities. By formulating these three functions, an improved multi-choice goal programming approach is proposed to solve the multi-objective optimization model, which is then compared with the goal attainment method. Finally, to demonstrate the applicability and feasibility of the proposed model, an illustrative example of healthcare waste management is analyzed and the results are discussed [19].

Negarande and Tajuddin (2022) presented a robust fuzzy multi-objective programming model for designing a sustainable hospital waste management network considering flexibility and uncertainty. In their paper, waste management in hospitals has been discussed by developing a new multi-objective mixed integer linear

programming model. The goal is to design a sanitary waste management network considering sustainability, flexibility and uncertainty. In order to deal with uncertainty, a robust fuzzy programming approach was used, and then an improved goal programming technique and Lp-metric method were proposed to solve the model [20].

Zhao et al. (2022) reviewed the emergency disposal and management of medical waste during the COVID-19 epidemic in China. In this research, they showed that mobile disposal facilities can dispose of infectious waste in situ even if most of their disposal capacity is at a low level (<5 tons per day). To dispose of high volumes of emergency waste, joint disposal facilities should be completely modified where separate feeding systems should be considered. In particular, municipal solid waste incineration facilities have great potential to improve sanitary waste emergency disposal capacities. For hazardous waste incineration facilities, the compatibility of the waste must match the composition and calorific value of the waste. Also, things like collection, classification, packaging, transportation and disposal are necessary for centralized disposal companies [21].

In a review article, Andibo et al. (2022) investigated the management of medical waste due to the Covid-19 pandemic and their management and environmental effects in Australia. This study examines the different management and disposal practices adopted in Australia to deal with medical waste arising from the COVID-19 pandemic and its impacts on public health and the environment. To achieve the objectives of this study, previous studies from 2019 to 2021 have been collected and analyzed from various databases. This study focuses on the generation of medical waste caused by COVID-19, management and disposal methods, current problems/challenges, and environmental and public health impacts. Given the enormous risks and importance of proper management and disposal of medical waste from COVID-19, this study provides insights into short- and long-term responses to the management of COVID-19 waste in Australia. This study will contribute to Australia's efforts against the transmission and spread of COVID-19 and provide recommendations for developing viable and sustainable strategies to mitigate similar epidemics in the future [22].

Ochoa-Barragán et al. (2023) have designed a mathematical optimization strategy for optimal municipal solid waste management in the context of the COVID-19 epidemic. The strategy that they have provided integrates optimization and machine learning models. The optimization model determines the optimal supply chain for the municipal waste management system. Then, machine learning prediction models estimate the required parameters over time, which helps generate future projections for the proposed strategy. Moreover, a case study of New York City was addressed to evaluate the proposed strategy, which includes extensive socioeconomic data sets to train the machine learning model. The results showed trade-offs between the economic (profit) and environmental (waste sent to landfill) objectives for future scenarios, which can be helpful for possible pandemic scenarios in the following years [28].

UL Ain et al. (2023) used the meta-analysis to analyze diverse range of hospital waste management practices in Pakistan through a review article. They reviewed literature review of hospital waste management by reading papers which had been indexed in Web of Science, Scopus and The results showed that infectious and non-infectious waste which had been generated around Pakistan were a dramatic factor contributing the spread of Covid-19 during the pandemic [29].

Table 1. Health waste management research

Reference	Multi-level	Multi-product	Location	Routing	Multi-period	Sustainability dimensions	Risk	Energy production	Covid-19	Multi-objective	Solution method
[1]	√	√		√							Bat algorithm
[2]	√		√								Bee algorithm
[3]											Regression
[4]											Review
[5]		√	√	√			√			√	Genetic algorithm
[6]			√		√	Environmental	√		√	√	Lingo
[7]	√		√								MCDM
[8]			√		√	Environmental	√		√	√	Lingo
[9]	√		√		√	Environmental	√		√	√	GM(1) Gray
[10]	√		√		√	Environmental	√				GAMS and CPLEX
[11]	√		√						√		Heuristic
[12]	√		√						√		Cuckoo algorithm
[13]			√								MCDM
[14]		√	√		√	Environmental	√		√	√	Heuristic
[15]	√	√	√	√	√	Environmental	√		√	√	Ideal programing
[16]	√			√					√		Simulated Annealing algorithm
[17]	√		√	√	√		√		√	√	Expansion Planning
[18]	√	√	√			Environmental			√	√	Heuristic
[19]	√		√		√	Triple dimensions				√	Goal planning
[20]	√		√		√	Environmental				√	LP-metric
[21]	√					Environmental			√		Review
[22]						Environmental					Review
[23]		√	√			Environmental	√			√	Waterfall optimization algorithm
[24]	√	√	√	√	√	Environmental	√			√	Imperialist Competitive Algorithm - ICA

[28]	√		√			Economic and environmental			√		Machine learning and mathematical modeling
[29]									√		Review
This paper	√	√	√	√	√	Triple dimensions	√	√	√	√	Horse herd optimization algorithm and NSGA-II

As it can be seen from table 1 and the research background section, it was observed that so far and especially in recent years, many people have investigated the management of health (hospital) waste and have presented a mathematical model for this problem. Among the previous researches, we can refer to the article of Valizadeh et al. (2021) who designed a multi-level, multi-product and multi-period supply chain network for the management of sanitary waste in the period of Covid-19 and presented a multi-objective mathematical model considering Risk taking and environmental considerations for the problem. The problem of the present research is based on the article of Valizadeh et al. (2021) and in addition to the items considered in the mentioned article, the three dimensions of sustainability, risk, routing of vehicles, energy production, employment and emission of polluting gases are also considered. In this research, a multi-objective mathematical model with fuzzy parameters is presented for the described problem and the horse herd optimization algorithm and NSGA-II will be used to solve it.

Therefore, the innovation of the current research compared to the previous research and the article of Valizadeh et al. (2021) is in the following cases:

- Providing an integrated multi-objective location-routing model for the supply chain of waste management in pandemic conditions.
- Considering the dimensions of sustainability (economic dimension: minimization of system costs, including the cost of locating and the cost of collecting, recycling and burning waste to produce energy; environmental dimension, including minimizing the emission of pollutants in the transportation and processing system in various facilities as well as maximizing the production of electrical energy; the social dimension including minimizing the risk of contracting the virus and maximizing the amount of employment created in the centers).
- Solving the integrated multi-objective location-routing model for the supply chain of waste management in pandemic conditions using meta-heuristic algorithms.

3. Problem description and modeling

In the investigated problem, for better management of hospital waste, especially during an epidemic like COVID-19, the waste is classified into two categories of infectious and non-infectious waste. It is assumed that waste in hospitals and health centers is separated and placed in infectious and non-infectious waste bins. Medical waste is collected from hospitals and health centers, and then infectious waste is sent to incineration centers and non-infectious waste is sent to recycling centers.

Infectious waste is converted into electrical energy using a waste incinerator, and the MW waste is returned to the production cycle in the industry after recycling. One of the cases considered in the problem is the risk of people

contracting the virus due to the presence of garbage and their transportation to different centers. Among the non-infectious wastes, some are recyclable and some are not. Therefore, after collecting in collection centers, they are separated and sent to recycling centers or waste incinerators based on their type.

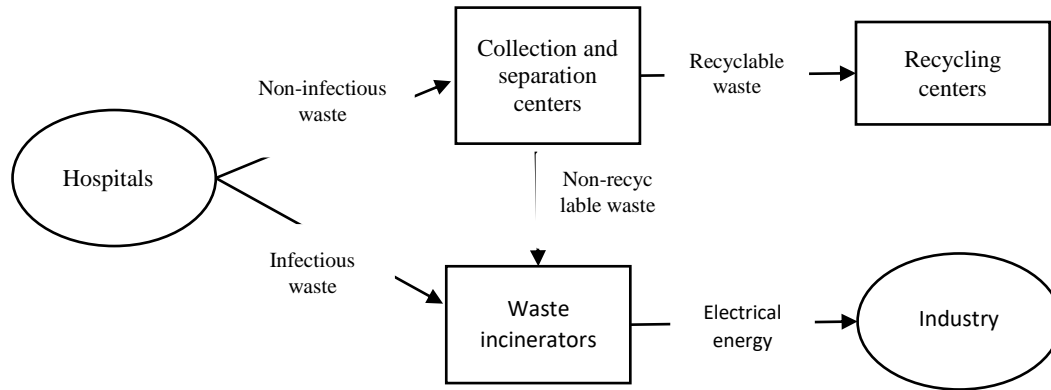


Figure 1. Conceptual model

In this article, a multi-objective mathematical model is presented for the integration of location-routing decisions in the supply chain of hospital waste management in which the modeling assumptions are as follows:

- Segregation of waste at source prevents all waste from becoming viral and helps reduce the spread of viruses through waste. After separation, the waste is divided into two categories: hazardous infectious waste (non-recyclable and converted into energy) and non-hazardous waste (recyclable).
- The risk of spreading viruses is relatively equal for each type of waste (infectious and non-infectious waste).
- Two types of vehicles are considered for transporting waste, the first type carries non-infectious waste and the second type carries infectious waste.
- The number of cars, people collecting waste and the capacity of waste incinerators are considered constant in this study. In other words, we cannot import a new vehicle or person.
- After completing their duty in each center, the vehicles return to collection centers or hospitals (as needed) and perform their duties again. Therefore, in this research, vehicle routing is also considered.
- The weight and volume capacity of vehicles is considered limited.
- The construction of facilities at any point creates employment.
- Some parameters of the model, such as the amount of waste produced in hospitals, are uncertain and are considered as fuzzy numbers.
- Emission of polluting gases from transportation using vehicles is also considered in this model.
- The mathematical model is multi-objective, whose objectives are to optimize the three dimensions of sustainability (economic, social and environmental).
- The economic goal is to minimize the costs of the system, including the cost of location, the cost of recycling, collection, separation of a non-infectious waste and incineration.

- The environmental goal includes minimizing the emission of pollutants in the transportation and processing system in various facilities, as well as maximizing the production of electrical energy.
- The social goal includes minimizing the risk of contracting viruses and maximizing the amount of employment created in the centers.

3.1. Mathematical model

In the continuation of this section, we have discussed the mathematical model for the described problem, in this regard, first the indexes, parameters and variables of the research and then the main structure of the model have been presented.

a) Indexes

I : Number of hospitals and $i \in I$

M : The set of potential points for collection and separation centers $m \in M$

P : The set of potential points for recycling centers $p \in P$

N : The set of potential points for waste-burning center $n \in N$

S : Number of waste collection $s \in S = 1, 2$ (1: infectious and 2: non-infectious waste)

K : Number of vehicles carrying garbage $k \in K$

K' : Number of non-infectious waste transport vehicles $k' \in K'$

T : period index $t \in T$

b) Parameters

\tilde{d}_{it}^s : The amount of infectious waste type s produced by hospital i in period t (the amount of fuzzy demand of hospitals to collect the waste produced by them).

\tilde{f}_m : The fuzzy cost of running a collection and separation center at location m .

\tilde{f}_p : The fuzzy cost of running a recycling center at p .

\tilde{f}_n : The fuzzy cost of running a waste incineration center at location n .

w_k : The weight of vehicle k .

w_c : The weight of pollutant gases emitted per liter of fuel.

p_c : Average price per unit of released gas.

p_f : The price of a unit volume of fuel.

v_f : Volume of fuel consumption per unit of distance, weight, speed and distance.

α_k : The $k - th$ vehicle speed change factor per unit of weight.

v_k : The speed of vehicle k .

w_s : Waste weight.

vol_s : Waste volume.

C_s : The cost of separating a unit of non-infectious waste.

c_m : The cost of collecting an infectious and non-infectious waste (per unit).

c_p : The cost of recycling a unit of non-infectious waste.

c_n : The cost of burning a unit of infectious or non-infectious waste.

E : The average energy produced by burning a unit weight of infectious waste.

Risk: The average risk of contracting the virus due to not managing a weight unit of hospital waste.

θ_m : The number of employed workers in the case of establishing a collection and separation center in m .

θ_p : The number of workers employed in the case of establishing a recycling center in the place of p .

θ_n : The number of employed workers in case of establishment of waste incineration center in place n .

$L_{i1,i2}$: The distance between hospital $i1$ and hospital $i2$.

L_m : The average distance between hospitals and the collection and separation center m .

L_{mp} : The distance between the collection and separation center m and the recycling center p .

L_{mn} : The distance between the collection and separation center m and the waste incineration center n .

L_{in} : The distance between the hospital i and the waste incineration center n .

QW_k : Weight capacity of the vehicle k .

QV_k : Volumetric capacity of the vehicle k .

c) Variables

Binary variables:

z_m : If the collection and separation center is established at point m , it is equal to 1 and otherwise it is equal to 0.

z_p : If the recycling center is established at point p , it is equal to 1 and otherwise it is equal to 0.

z_n : If the waste incineration center is established at point n , it is equal to 1 and otherwise it is equal to 0.

y_{i1i2k}^t : If the vehicle k goes from hospital $i1$ to hospital $i2$ in period t , it is equal to 1 and otherwise it is equal to 0.

y_{ink}^t : It is equal to 1 if the vehicle k goes from hospital i to waste-burning center n in period t and otherwise it is equal to 0.

y_{imk}^t : It is equal to 1 if the vehicle k goes from hospital i to collection and separation center m in period t and otherwise it is equal to 0.

y_{mnk}^t : If the vehicle k goes from the collection and separation center m to the waste-burning center n in period t , it is equal to 1 and otherwise it is equal to 0.

y_{mpk}^t : If the vehicle k goes from the collection and separation center m to the recycling center p in period t , it is equal to 1 and otherwise it is equal to 0.

Non-binary variables:

xw_{i1i2k}^{ts} : Amount of waste s by the vehicle k traveling from hospital $i1$ to hospital $i2$ in period t (before reaching hospital $i2$).

x_{ik}^{ts} : The amount of waste s that is received by vehicle k from hospital i in period t , to be sent to collection and separation centers.

x_{mk}^{ts} : The amount of waste s that is sent by vehicle k from hospitals to the collection and separation center m in period t .

x_{ink}^{ts} : Amount of waste s sent by vehicle k from hospital i to waste-burning center n in period t .

x_{mnk}^{ts} : The amount of waste s that is sent by vehicle k from the collection and separation center m to the waste-burning center n in period t .

x_{mpk}^{ts} : The amount of waste s sent by vehicle k from the collection and separation center m to the recycling center p in period t .

q_{is}^t : The amount of waste s in the hospital i that is not collected in period t (Amount of unanswered demand).

Based on modeling assumptions, indices, parameters and model variables, the main structure of the mathematical model is as follows:

$$\begin{aligned} \min z1 = & \sum_{m=1}^M \tilde{f}_m z_m + \sum_{p=1}^P \tilde{f}_p z_p + \sum_{n=1}^N \tilde{f}_n z_n + CS \times \sum_t \sum_m \sum_{k \in K'} x_{mk}^{t2} \\ & + \sum_t \sum_m \sum_{k \in K'} \sum_p C_p x_{mpk}^{t2} + \sum_t \sum_i \sum_{k \in K} \sum_n C_n x_{ink}^{t1} \\ & + \sum_t \sum_m \sum_{k \in K'} \sum_n C_n x_{mnk}^{t2} + \left(\sum_{k=1}^K (v_f * \alpha_k * v_k \right. \\ & * \left(\sum_{t=1}^T \sum_m (x_{mk}^{t2} * L_m) \times w_2 + \sum_{t=1}^T \left(\sum_{n=1}^N \sum_{i=1}^I x_{ink}^{t1} * L_{ni} * w_1 \right. \right. \\ & + \left. \sum_{m=1}^M \sum_{n=1}^N x_{mnk}^{t2} * L_{mn} + \sum_{m=1}^M \sum_{p=1}^P x_{mpk}^{ts} * L_{mp} * w_2 \right) + w_k) * (p_f \\ & \left. + w_c * p_c) \right) \end{aligned} \quad (1)$$

$$\max z2 = \sum_{t=1}^T \sum_{k=1}^{K'} \sum_{n=1}^N \sum_{i=1}^I E * x_{ink}^{t1} + \sum_{t=1}^T \sum_{k=1}^K \sum_{m=1}^M \sum_{n=1}^N E * x_{mnk}^{t2} \quad (2)$$

$$\min z3 = \sum_{t=1}^T \sum_{i=1}^I \sum_{s=1}^2 risk * q_{is}^t \quad (3)$$

$$\text{Max } z_4 = \sum_{m=1}^M \theta_m z_m + \sum_{p=1}^P \theta_p z_p + \sum_{n=1}^N \theta_n z_n \quad (4)$$

Subject to:

$$\sum_m \sum_k y_{imk}^t \geq 1 \quad \forall i, t \quad (5)$$

$$\sum_k \sum_i y_{imk}^t = \sum_k \left(\sum_p y_{mpk}^t + \sum_n y_{mnk}^t \right) \quad \forall m, t \quad (6)$$

$$\sum_k x_{ik}^{ts} + q_{is}^t = \tilde{d}_{is}^t \quad \forall i, t, s \quad (7)$$

$$\sum_k x_{mk}^{ts} = \sum_k \left(\sum_p x_{mpk}^{ts} + \sum_n x_{mnk}^{ts} \right) \quad \forall m, t, s \quad (8)$$

$$xw_{i1i2k}^{ts} \leq M \times y_{i1i2k}^t \quad \forall i1, i2, k, t, s \quad (9)$$

$$x_{ik}^{ts} \leq M \times y_{imk}^t \quad \forall l, m, k, t, s \quad (10)$$

$$x_{mpk}^{ts} \leq M \times y_{mpk}^t \quad \forall p, m, k, t, s \quad (11)$$

$$x_{mnk}^{ts} \leq M \times y_{mnk}^t \quad \forall n, m, k, t, s \quad (12)$$

$$x_{ink}^{ts} \leq M \times y_{ink}^t \quad \forall i, m, k, t, s \quad (13)$$

$$\sum_{i1 \in I} \sum_{i2 \in I} y_{i1i2k}^t \leq |N| - 1 \quad \forall N \in I: |N| \geq 2 \ \& \forall k, t \quad (14)$$

$$\sum_s (x_{mpk}^{ts} \times w_s) \leq QW_k \quad \forall m, p, k, t \quad (15)$$

$$\sum_s (x_{mpk}^{ts} \times vol_s) \leq QV_k \quad \forall m, p, k, t \quad (16)$$

$$\sum_s (x_{mnk}^{ts} \times w_s) \leq QW_k \quad \forall m, n, k, t \quad (17)$$

$$\sum_s (x_{mnk}^{ts} \times vol_s) \leq QV_k \quad \forall m, n, k, t \quad (18)$$

$$\sum_s (x_{ink}^{ts} \times w_s) \leq QW_k \quad \forall m, i, k, t \quad (19)$$

$$\sum_s (x_{ink}^{ts} \times vol_s) \leq QV_k \quad \forall m, i, k, t \quad (20)$$

$$\sum_s \left(\sum_i ((xw_{i1k}^{ts} \times y_{i1k}^t) + x_{i1,k}^{ts}) \times w_s \right) \leq QW_k \quad \forall i, k, t \quad (21)$$

$$\sum_s \left(\sum_i ((xw_{i1k}^{ts} \times y_{i1k}^t) + x_{i1,k}^{ts}) \times vol_s \right) \leq QV_k \quad \forall i, k, t \quad (22)$$

$$\sum_s (x_{mk}^{ts} \times w_s) \leq QW_k \quad \forall m, k, t \quad (23)$$

$$\sum_s (x_{mk}^{ts} \times vol_s) \leq QV_k \quad \forall m, k, t \quad (24)$$

$$\sum_m z_m \geq 1 \quad \forall m \quad (25)$$

$$\sum_p z_p \geq 1 \quad \forall p \quad (26)$$

$$\sum_n z_n \geq 1 \quad \forall n \quad (27)$$

$$z_n, z_m, z_p, y_{i1,i2k}^t, y_{imk}^t, y_{ink}^t, y_{mnk}^t, y_{mpk}^t = \{0,1\} \quad \forall n, m, p, i, k, t \quad (28)$$

$$x_{mk}^{ts}, xw_{i1,i2k}^{ts}, x_{i,k}^{ts}, x_{ink}^{ts}, x_{mnk}^{ts}, x_{mpk}^{ts}, q_{is}^t \geq 0 \quad \forall n, m, p, i, i1, i2, s, k, t \quad (29)$$

Expression (1) represents the first objective function, which is to minimize the costs of running facilities and waste processing in centers, vehicle fuel costs, and environmental costs resulting from the emission of polluting gases. Expression (2) represents the second objective function and it is the maximization of the energy produced by burning waste. Expression (3) represents the third objective function of the model, which is to minimize the risk of contracting the virus of non-management of waste (garbage that has not been collected and managed in each period). Expression (4) represents the fourth objective function of the model, which is to maximize the employment of labor in the established centers.

Constraint (5) guarantees that all hospitals are visited by at least one vehicle in each period. Constraint (6) shows that the vehicles entered into the collection and separation centers must leave these centers. Constraint (7) calculates the amount of unanswered or uncollected waste demand of hospital i for waste s in period t . Constraint (8) guarantees the balance of waste flow in nodes. Constraints (9) to (13) guarantee that if waste is sent from one center to another center by a vehicle that has traveled between the two by that vehicle. Constraint (14) prevents the creation of sub-tours during the travel of vehicles between hospitals. Constraints (15) to (24) guarantee that the waste carried by vehicle k does not exceed its weight and volume. Constraints (25), (26) and (27) ensure that at least one center is established for collection, waste-burning and recycling facilities. Constraints (23) and (24) represent the permissible and feasible values of the model variables.

In the developed model in this section, facility construction costs and demand parameter are considered fuzzy, and in this article, they are assumed to be triangular fuzzy numbers. Several methods have been proposed to solve fuzzy mathematical programming problems. In this research, the ranking method provided by Jimenez et al. (2007) has been used. Jimenez proposed a method of ranking fuzzy numbers based on the comparison of their expectation intervals. And by using the mentioned method, we convert the provided fuzzy programming model to its deterministic model by replacing the following expression in the model.

The definite form of the first objective function:

$$\begin{aligned} \min z1 = & \sum_{m=1}^M \frac{f_m^1 + 2f_m^2 + f_m^3}{2} z_m + \sum_{p=1}^P \frac{f_p^1 + 2f_p^2 + f_p^3}{2} z_p + \sum_{n=1}^N \frac{f_n^1 + 2f_n^2 + f_n^3}{2} z_n + CS \quad (30) \\ & \times \sum_t \sum_m \sum_{k \in K'} x_{mk}^{t2} + \sum_t \sum_m \sum_{k \in K'} \sum_p C_p x_{mpk}^{t2} + \sum_t \sum_i \sum_{k \in K} \sum_n C_n x_{ink}^{t1} \\ & + \sum_t \sum_m \sum_{k \in K'} \sum_n C_n x_{mnk}^{t2} + \left(\sum_{k=1}^K (v_f * \alpha_k * v_k * \left(\sum_{t=1}^T \sum_m (x_{mk}^{t2} * L_m) \right) \times w_2 \right. \\ & + \sum_{t=1}^T \left(\sum_{n=1}^N \sum_{i=1}^I x_{ink}^{t1} * L_{ni} * w_1 + \sum_{m=1}^M \sum_{n=1}^N x_{mnk}^{t2} * L_{mn} + \sum_{m=1}^M \sum_{p=1}^P x_{mpk}^{ts} * L_{mp} * w_2 \right) \\ & \left. + w_k \right) * (p_f + w_c * p_c) \end{aligned}$$

Constraint transformation (7):

$$\sum_k x_{ik}^{ts} + q_{is}^t = (1 - \alpha) \frac{d_{is}^{t,1} + d_{is}^{t,2}}{2} + \alpha \frac{d_{is}^{t,2} + d_{is}^{t,3}}{2} \quad \forall i, t, s \quad (31)$$

4. The Solution Approach

In the present research, firstly a four-objective mathematical model is presented, and as inverse logistics problem is NP-HARD (Jiao et al., 2019), horse herd optimization algorithm is used to solve the model. We evaluate HOA's performance by comparing the purposed algorithm's results with the well-known NSGA-II algorithm.

The HOA algorithm imitates the social behaviors of horses at various ages by utilizing six key features: Grazing (G), Hierarchy (H), Sociability (S), Imitation (I), Defensive mechanism (D), and Roaming (R). The HOA algorithm

is based on these tendencies and was introduced by Miarnaeimi, et al. (2020) [30]. This algorithm imitates the social performances of horses at different ages using six important features: grazing, hierarchy, sociability, imitation, defense mechanism and roam. The flowchart of this algorithm is as shown below, for more information regarding the calculation of different steps, refer to reference [30].

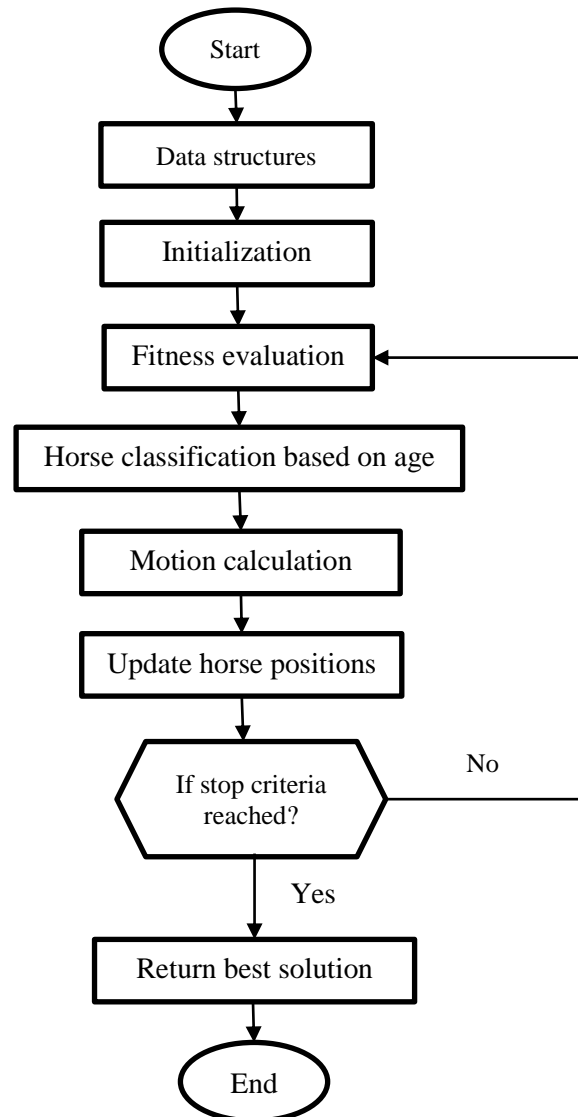


Figure 2. Flowchart of HOA [30]

4.1. The proposed structure of HOA

In the previous section, the general structure of the horse herd optimization algorithm is presented. In this research, we have designed the HOA algorithm based on the Pareto archive to solve the multi-objective model as the pseudo code below.

```

{
Initial bound variables and other parameters.

Generate N feasible solutions as initial population by providing uniform random distribution of horses in the
feasible space.
  
```

Apply improvement procedure on initial solutions.

Apply feasibility check procedure for improved solutions.

Initialize the adaptive Pareto Archive so that it is empty.

While a given maximal number of iterations is not achieved

Check fitness by eq. (32).

Calculation the age of α, β, γ and δ horses based on [30].

Applying velocity to each horse by age based on [30].

Update horse's positions in the search space.

Improve horse herd in current population of algorithm.

Apply feasibility check procedure.

Update Pareto Archive.

Select N solutions whit higher quality and higher diversity as population for next generation.

End while

}

Return Pareto Archive.

}

4.2. Solution representation

In all meta-heuristic algorithms, due to the need for a feasible solution at the beginning of the work, it is necessary to store the solution according to a specific structure, which is called the way of displaying the answer. In this article, due to display variables, we use matrix. Each answer contains several matrixes, which are designed according to the outputs of the model. For example, for the variables z_m , z_n and z_p , row matrixes (one-dimensional) whose number of rows is equal to the number of M , N and P (the number of potential points for positioning) are defined. To display the variable y_{ink}^t , a 4-dimensional matrix is used whose dimensions are $I \times N \times K \times T$. Besides, some matrixes are considered for other variables in the same way based on their indices.

4.3. Solution initialization method

In this research, a parallel neighborhood search method is used to generate initial solutions.

Most evolutionary meta-heuristic methods use a random approach to generate initial solutions. But since the quality of the final solutions obtained from these methods is directly dependent on the quality of the initial produced solutions, in this article, a parallel local search method with 3 neighborhood search operations are used to generate feasible solutions.

In each of the neighborhood search functions, an answer is sent to the corresponding function as an initial answer, and in step 1, the corresponding operator is applied on the answer and the neighborhood of the answer is obtained.

After generating all the neighborhood answers, according to (Deb et al., 2002) [31], the answer with higher quality and higher diversity is selected and if it is not repeated, it is added to the population of initial answers. In the following, first the search operators for the answer and then their parallel combination as a parallel neighborhood search procedure are described.

Description of the 3 local search functions:

- Operator 1: two indexes $m1$ and $m2$ are randomly generated in the uniform interval $[1..M]$ (M potential number of collection and separation centers) and in the variable answer matrix z_m , the values of the houses $m1$ and $m2$ are exchanged with each other. Then, according to the change of established collection and separation centers, other variables are modified.
- Operator 2: two indices $p1$ and $p2$ are randomly generated in the uniform interval $[1..P]$ (P the potential number of recycling centers) and in the variable answer matrix z_p , the values of the houses $p1$ and $p2$ are exchanged with each other. Then, according to the change of established recycling centers, other variables are modified.
- Operator 3: two indexes $n1$ and $n2$ are randomly generated in the uniform interval $[1..N]$ (N potential number of waste-burning center) and in the variable answer matrix z_n , the values of houses $n1$ and $n2$ are exchanged with each other. Then, according to the change of established waste incineration centers, other variables are modified.

The described 3 neighborhood operators are applied in parallel on the generated in iteration. For each solution, several neighboring solutions that are local optimal in the neighborhood of that solution are reported. The reported answers are selected according to [31], the answer with higher quality and higher diversity, and as described before, if it is not repeated, it is added to the answer population.

Assume that the number of solutions available in each iteration of the horse herd optimization algorithm is represented by NP , this value is constant during the optimization process. In order to generate the desired initial NP solutions, the designed parallel neighborhood search algorithm should generate NP non-recursive solutions. This algorithm uses a predetermined feasible solution as the initial solution. At first, the proposed method gives the existing answer as an input to the parallel neighborhood search structure and selects an answer as an output and adds it to the population of answers if it is not repeated. This process continues until the algorithm reaches the termination condition. The structure of the parallel neighborhood search method is as follows:

Step 0- Set the counter equal to zero.

Step 1- Give the input answer (s) to the first neighborhood operator and name the output $s1$.

Step 2- Give the input answer (s) to the second neighborhood operator and name the output $s2$.

Step 3- Give the input answer (s) to the third neighborhood operator and name the output $s3$.

Step 4- Among the answers $s, s1, s2$ and $s3$, choose the answer with higher quality and higher dispersion according to [31].

Step 5- Name the selected answer s.

Step 6- Add one unit to the counter.

Step 7- If the counter value does not exceed the maximum limit, go to step 1 and otherwise go to step 8.

Step 8- The end.

4.4. Improvement procedure

In the proposed HOA, an improvement procedure is designed to improve the previous step's selected solutions. Spiritual output solutions are selected as the collection of iterations after the algorithm. The improved solutions are considered as the population of the next iteration of the algorithm. The proposed improvement procedure is based on the variable neighborhood search (VNS). VNS uses 3 neighborhood search structures which just explained.

These structures are applied in the form of VNS, and its general structure is as follows [32,33]:

The pseudo-code of our VNS is as follows:

{For each input solution

K=1

While stopping criterion is meet do

 New solution=Apply NSS type k

 If *new solution is better*, then

 K=1

 Else

 K=k+1

 If k=4 then

 K=1

 Endif

Endif

Endwhile

}

Each solution of the population enters the VNS algorithm, a solution obtained as an output, and the correction procedure, then applied to the rest of the solution matrices, and they replaced by the input solutions.

The general structure of the improvement procedure is as follow:

Improvement method

{For each s_i in input population

S_i =apply VNS procedure on s_i .

S_i =check feasibility method.

}

4.5. Calculating fitness

In the horse herd optimization algorithm (HOA), we offer equation (32) to calculate the fitness of horses. Due to calculate fitness, all solutions or horse's positions are considered as a set and ranked using the rule of Deb et al., (2002) [31]. The crowding distance is calculated for each rank and then c_s criteria is calculated for each solution as its fitness.

$$c_s = \frac{\text{rank}}{\text{crowding distance}} \quad (32)$$

Since this operator requires both the rank and crowded distance of each solution in the population, we calculate these quantities according [31] and the lower the value of c_s for a solution, the higher the quality and diversity of that solution. Therefore, solutions which have less c_s criteria are marked with higher fitness [34].

4.6. Updating Pareto archive

In this research, the proposed solution method is based on the Pareto archive. The proposed algorithm provides a set called the Pareto archive, which contains the non-dominated solutions generated by the algorithm. This set is updated in each iteration of the algorithm. The generated solutions of the last iteration and the Pareto archive solutions are poured into a pool and ranked to update the set. Then, the first-ranked (non-dominated) solutions are selected and considered as a new Pareto archive.

4.7. Selecting the next-generation solutions

In each iteration, the algorithm requires a set of solutions. Therefore, to select the next iteration population, solutions of the last iteration and the newly generated solutions by the algorithm are poured into a solution pool. After ranking and calculating the crowding distance of solutions, N solutions with the highest quality and diversity are selected according to [31] as the population of the next iteration.

5. Computational results

As mentioned, in order to solve the mathematical model, the Horse Herd Optimization Algorithm (HOA) and Non-dominate Sorting Genetic Algorithm (NSGA-II) have been proposed. In this article, first of all in order to check the validity of the model and algorithm, the model is solved for a sample problem with a small size by ξ -constraint [35] and HOA, then the results are presented. After validating the model and algorithm, the HOA and NSGA-II algorithms were implemented in the MATLAB software environment and the results of the two mentioned algorithms have been compared with each other using comparative metrics.

5.1. Comparative metrics

For evaluating the proposed algorithms' efficiency, some criteria such as Quality Metric (QM), Spacing Metric (SM), and Diversity Metric (DM) [32,33,34].

Quality Metric: This criterion is equal to the number of Pareto (non-dominated) solutions.

Spacing Metric: This criterion calculates the uniformity of the distribution of the obtained Pareto solutions at the Pareto fronts, and it is defined as follows:

s

$$= \frac{\sum_{i=1}^{N-1} |d_{mean} - d_i|}{(N-1) \times d_{mean}} \quad (33)$$

Where d_i represents the Euclidean distance between two adjacent non-dominated solutions and d_{mean} represents the mean value of d_i .

Diversity Metric: This criterion is used to determine the number of non-dominated solutions of the optimal front. The definition of diversity metric is as follows:

$$D = \sqrt{\sum_{i=1}^N \max(\|x_t^i - y_t^i\|)} \quad (34)$$

Where $\|x_t^i - y_t^i\|$ represents the Euclidean distance between two adjacent solutions of x_t^i and y_t^i on the optimal front.

5.2. Test problems

In order to solve the model and evaluate the efficiency of the two algorithms, several sample problems have been designed, and these problems have been solved based on the data available in Tehran during the period of the Covid-19 epidemic in 2020. To design sample problems, attention has been paid to the number of hospitals in different areas of Tehran, as well as the potential collection, recycling and incineration points in this city. The necessary data to solve the model were also extracted from the database of hospital waste management in Tehran in 2020.

Table 2. Sample problems

Row	Number of hospitals	Number of collection centers	Number of recycling centers	Number of waste-burning centers	Number of vehicles for transporting infectious waste	Number of vehicles for transporting non-infectious waste	Number of periods (months)
1	10	3	3	3	5	5	12
2	10	4	3	3	10	10	12
3	10	5	4	3	5	5	12
4	15	3	3	3	10	10	12
5	15	4	3	3	5	5	12
6	15	5	4	3	10	10	12
7	20	3	3	3	10	10	12
8	20	4	3	3	15	15	12
9	20	5	4	3	10	10	12
10	20	6	4	3	15	15	12

5.3. Tuning parameters of algorithms and model

In order to implement the solution algorithms, the required parameters were set as follows:

- The population size for both algorithms is considered equal to 300.
- The stopping condition of the solving algorithm is the number of repetitions, which is considered equal to 500 for both algorithms.
- The rates of mutation and crossover operators in NSGA-II algorithm are set to 0.2 and 0.8, respectively.

Several parameters affect the performance of HOA, as it described in the Horse Optimization Algorithm section. Now the sensitivity analysis of the response to changes in parameters is performed, in order to gain a correct understanding of the effectiveness of these parameters. Changing the g (Grazing) factor has no significant effect on the resulting responses and only increases or decreases the search range of each horse. The following factors are examined in sensitivity analysis [31]:

- Hierarchy factor for β and γ horses (h_β and h_γ);
- Sociability factor for β and γ horses (s_β and s_γ);
- Imitation factor for γ horses (i_γ);
- Defense factor for α, β and γ horses (d_α, d_β and d_γ);
- Roam factor for δ and γ horses (r_δ and r_γ);

According to [31], the coefficients were changed from 0.1 to 1 with a step of 0.1 and the algorithm was run on the spherical function in 500 dimensions, in each case. The best values for the coefficients are including:

- h_β and h_γ are equal to 0.8 and 0.4, respectively;
- s_β and s_γ are equal to 0.2 and 0.1, respectively;
- i_γ is equal to 0.4;
- d_α, d_β and d_γ are equal to 0.6, 0.2 and 0.2, respectively;
- r_δ and r_γ are equal to 0.2 and 0.04, respectively.

In adjusting the parameters of the model, the data available in the hospital waste management system of Tehran during the period of Covid-19 in 2020 were used. As seen in the mathematical model, some parameters of the model are triangular fuzzy numbers. In order to generate triangular numbers related to each of the fuzzy ($m1, m2, m3$), first $m2$ is generated, then a random number r is generated in the interval (0,1), $m1$ using the relationship $m2 \times (1 - r)$ and $m3$ will also be produced using the relationship $m2 \times (r + 1)$. The direction of fuzzy parameters $m2$ is determined and two values $m1$ and $m3$ are determined using MATLAB software. For this reason, in the setting of these parameters, we only mention the value of $m2$.

- In each period, the amount of demand of hospitals for waste collection has been taken into account as a triangular fuzzy number ($m1, 100000, m3$) (100000 kg).

- The cost of establishing waste incineration centers equal to the fuzzy number $(m1,500,m3)$, the cost of establishing collection equal to the fuzzy number $(m1,100,m3)$ and recycling centers as triangular fuzzy number $(m1,1500,m3)$ in consideration have been taken
- Distances between facilities are randomly generated in a uniform interval $[1. .50]$ (50 km).
- The cut-off value for ranking fuzzy numbers is considered equal to 0.8.

5.4. Model validation results

As it has been mentioned, firstly, we choose a small-sized problem to be solved by ξ - constraint [35] and HOA. In order to this, we solved problem 1 in table (2) which related results are shown in table (3).

Table 3. Model and HOA's validity check

Method	Objective 1	Objective 2	Objective 3	Objective 4
ξ - constraint	40342	275	3.17	1.119
HOA	41007	281	3.92	1.363

As can be seen in table (3), the results of the two methods are displayed based on the values of the objective functions. It should be noted that for both methods, the solutions with the highest quality and the highest diversity is selected based on equation (32).

The results of the objective function values show that the solutions of the two methods are non-dominated to each other and are at the same level in terms of quality. Due to the fact that the ξ - constraint method is solved in Gams as an exact method, it can be said:

- 1- The presented mathematical model is valid, because it is solvable and has feasible solutions.
- 2- The HOA is valid and converges towards the optimal solution, because it has produced solutions at the quality level of the exact method.

5.5. Results of solving sample problems

In the following steps of this article, we solved the sample problems (table 2) by HOA and NSGA-II. The results of these algorithms are compared using QM, DM and SM as comparison's metrics. The results are shown in table 4.

Table 4. The results of HOA and NSGA-II

Prob.	HOA			NSGA-II		
	Quality metric	Spacing metric	Diversity metric	Quality metric	Spacing metric	Diversity metric
1	70	0.77	1278.1	30	0.73	998.6
2	99	0.95	1721.5	1	0.73	1207.8
3	77	1.02	2169.9	23	0.85	1681.5
4	100	0.88	2906.5	0	0.54	1800.7
5	84.49	0.79	3517.2	15.51	0.52	2339.3

6	82	0.99	4009.6	18	0.78	2998.2
7	70.40	0.89	4565.9	29.60	0.71	3452.1
8	91	0.87	4883.7	9	0.72	3843.6
9	77.1	1.12	5704.4	22.9	0.96	4279.5
10	83.2	1.09	6120.7	16.8	0.56	5089.3

Table (4) shows the comparison of the results of two algorithms based on the comparative indicators of quality, diversity and spacing. In this table, it can be seen that for all sample problems, the value of the quality and diversity indices obtained for the multi-objective HOA are greater than the similar values calculated for the NSGA-II algorithm, which indicates the high ability and power of the multi-objective HOA to touch the solutions with higher qualities compared to NSGA-II. Moreover, HOA has higher ability than NSGA-II to explore and extract the feasible space of the solution. Also, the value of the spacing metric shows that in most cases, the NSGA-II algorithm searches the solution area more uniformly than HOA.

Also, in order to compare the execution time of two algorithms, all problems were executed and the execution time of one iteration of each algorithm was calculated when solving these problems, the values can be seen in Table (5). This table shows that the computational time of the multi-objective HOA is higher than the NSGA-II algorithm. The execute time of the proposed HOA in solving the presented model can be justified by the different structures of neighborhood search and improvement procedure.

Table 5. Computational times (in second)

Prob.	Run time	
	HOA	NSGA-II
1	0.34	0.12
2	0.37	0.15
3	0.42	0.21
4	0.62	0.30
5	0.75	0.47
6	1.74	0.89
7	2.86	0.77
8	4.11	1.023
9	6.76	2.32
10	7.5	4.60
11	10.37	6.023
12	15.49	7.72
13	22.70	10.53
14	30.16	14.67

6. Conclusion

In this article, the presentation and solution of a multi-objective mathematical model for the reverse supply chain of hospital waste management during the corona epidemic in Iran has been discussed. In this regard, after designing the model, two multi-objective horse herd optimization algorithm (HOA) based on Pareto archive and NSGA-II have been used to solve the model. The results of solving the model showed that the proposed HOA, which is designed in combination with VNS, is able to solve the model and achieve optimal boundary solutions. Because the comparison of the results of this algorithm with the results of the well-known NSGA-II algorithm showed that the quality of the solution produced by the HOA is better than the NSGA-II algorithm. The comparison of the diversity metric of two algorithms shows that the HOA searches more points of the solution space, and for this reason, the probability of getting stuck in the local optimum is lower than the NSGA-II algorithm. On the other hand, the spacing metric of the NSGA-II algorithm is lower than that of the HOA (the lower this index is, the better), so it can be said that the multi-objective genetic algorithm searches the solution space more uniformly. From the point of view of the execution time of the two algorithms, it was shown that the NSGA-II algorithm solved the model in less time. Also, the increasing trend of execution time in both algorithms is another confirmation of NP-HARD problem of hospital waste management.

There are some recommendations for future research:

- (i) In this article, only waste management in hospitals was considered, however, during the Covid-19 pandemic, many patients were hospitalized and treated at home. Therefore, hospital waste in an epidemic period is not limited only to hospitals. In order to conduct future research, it is suggested that researchers add the collection of hospital waste from residential houses to the model.
- (ii) In the future, in addition to the reverse supply chain, the direct supply chain can also be considered and the production and distribution of health goods can also be modeled.
- (iii) We modeled uncertainty with fuzzy logic, in the future, it is suggested that researchers consider gray or probabilistic uncertain parameters.
- (iv) In future research, other meta-heuristic methods such as multi-objective particle swarm optimization algorithm, multi-objective whale optimization algorithm, etc. can be used and their performance can be compared with the horse herd optimization algorithm.
- (v) It is suggested that the present research model be solved for the data of other countries as well.

Declarations

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Conflict of Interest

The authors declare that they have no conflict of interest.

Consent for Publication

The authors declare that they consented to the publication of this study.

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